

MODELLING NON-LINEARITIES BEYOND VANILLA Λ CDM

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In collaboration with:

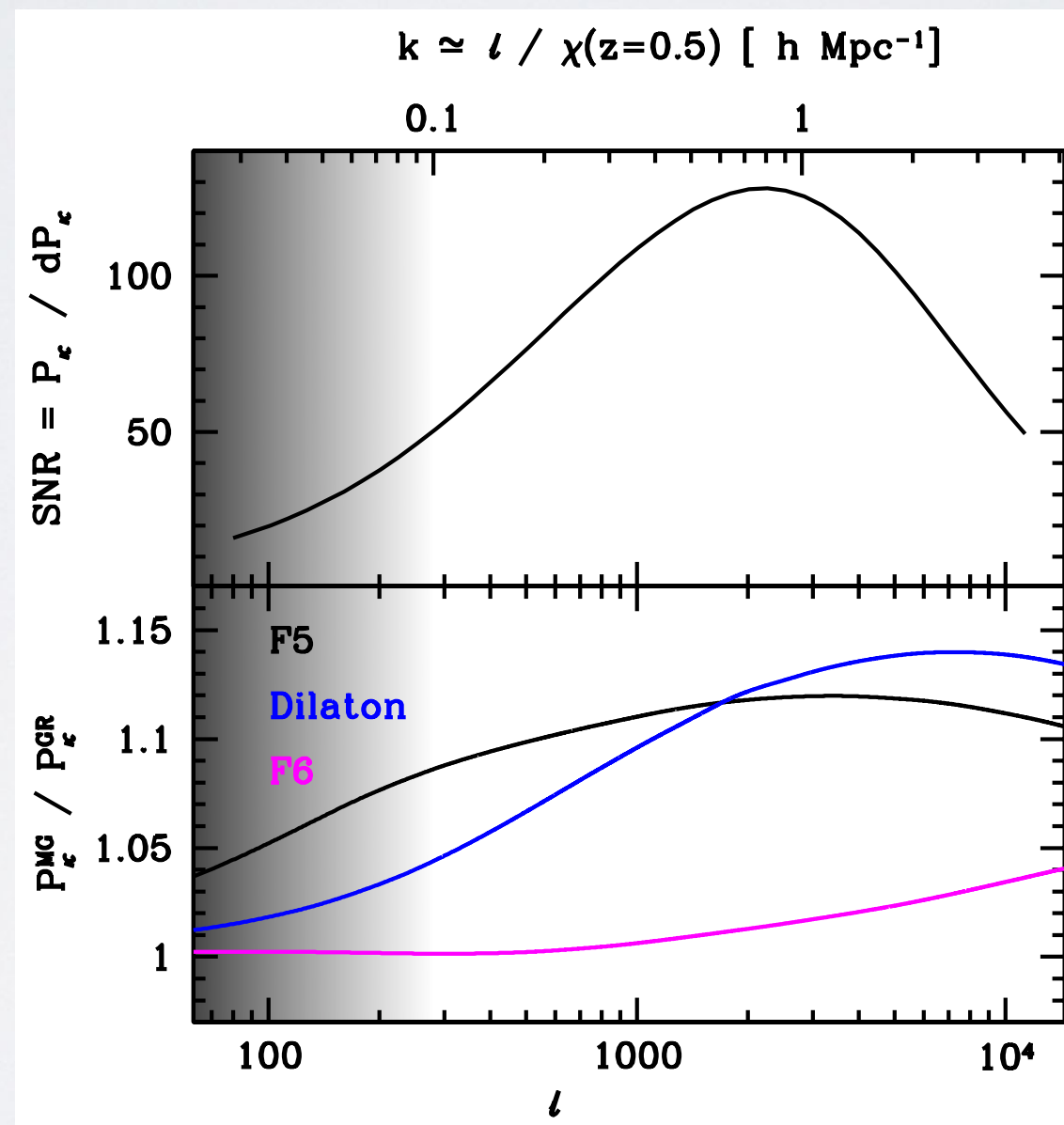
Alex Barreira, Sownak Bose, JD Emberson, Joachim Harnois-Deraps,
Catherine Heymans, Derek Inman, Baojiu Li, Lucas Lombriser, Alex Mead



Why Going Nonlinear?



Future LSS measurements will reach 1% precision

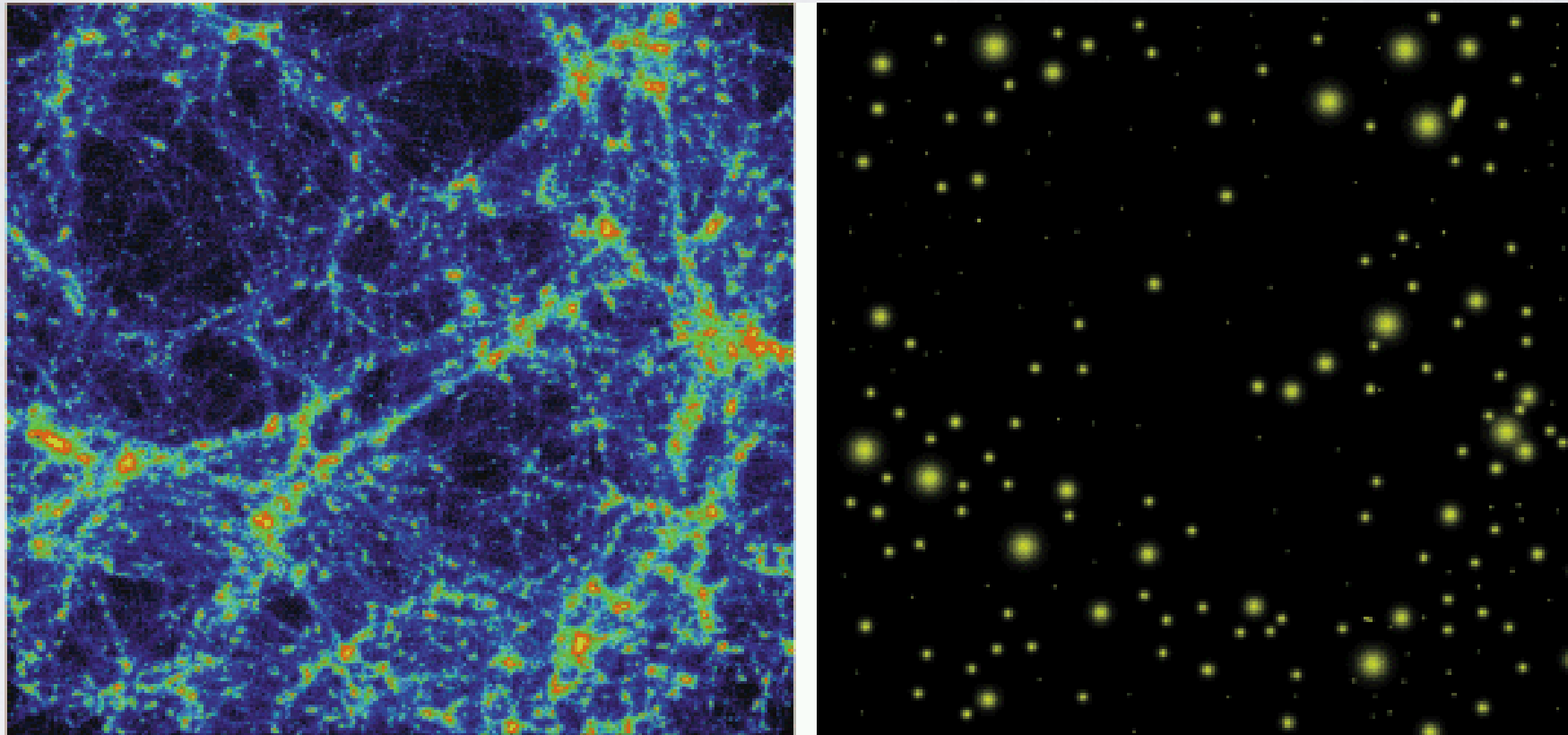


Nonlinear Predictions

- * Fast
- * Versatile
- * Accurate



The Halo Model



Cooray & Sheth 2002

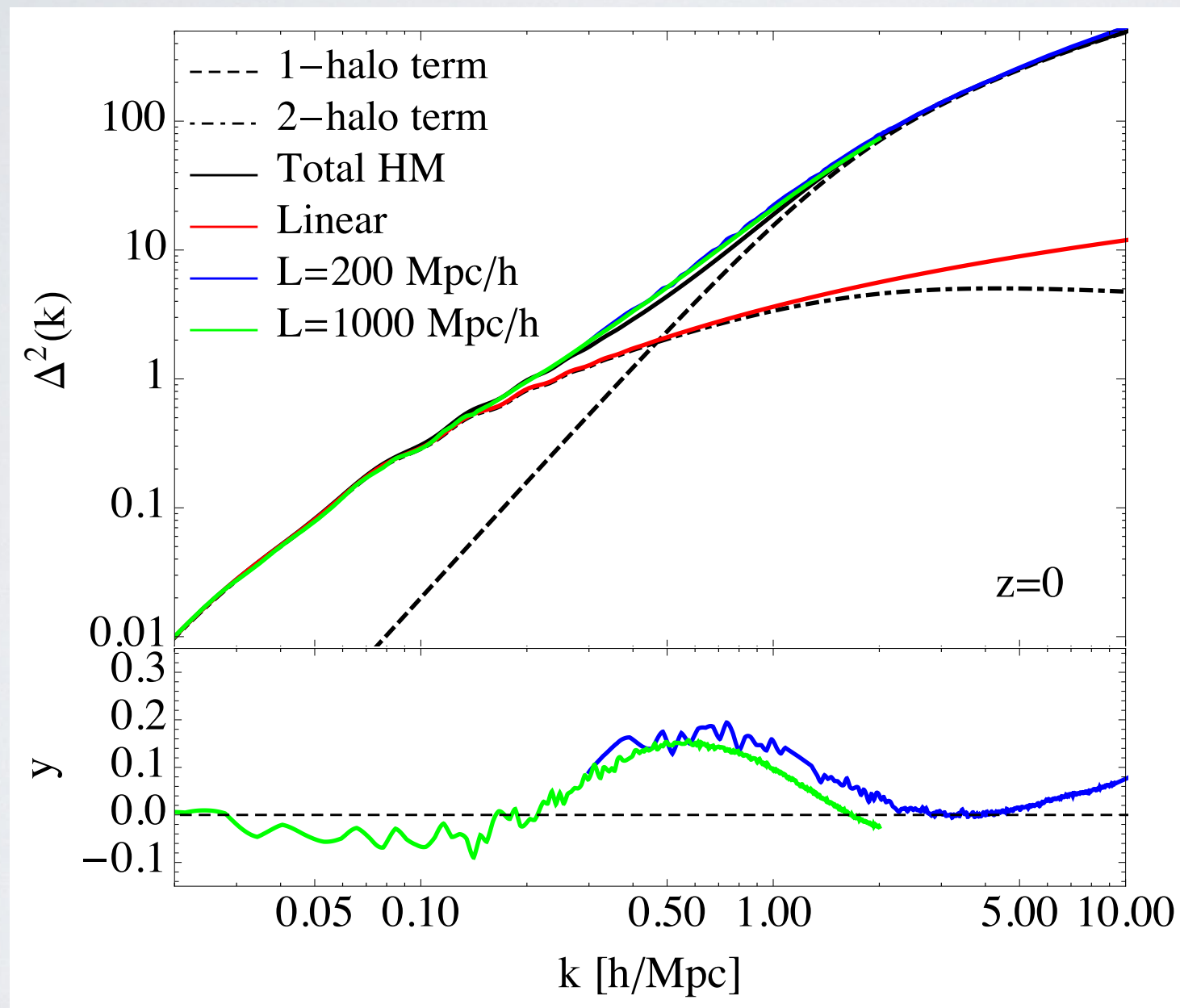
$$P(k) = P_{2h}(k) + P_{1h}(k)$$

(quasi)linear PT



- halo mass function
- virial overdensity
- halo concentrations

The Halo Model



- ☒ Fast
- ☒ Versatile
- ☒ Accurate

Halo Model Reactions

1) *Pseudo* cosmology

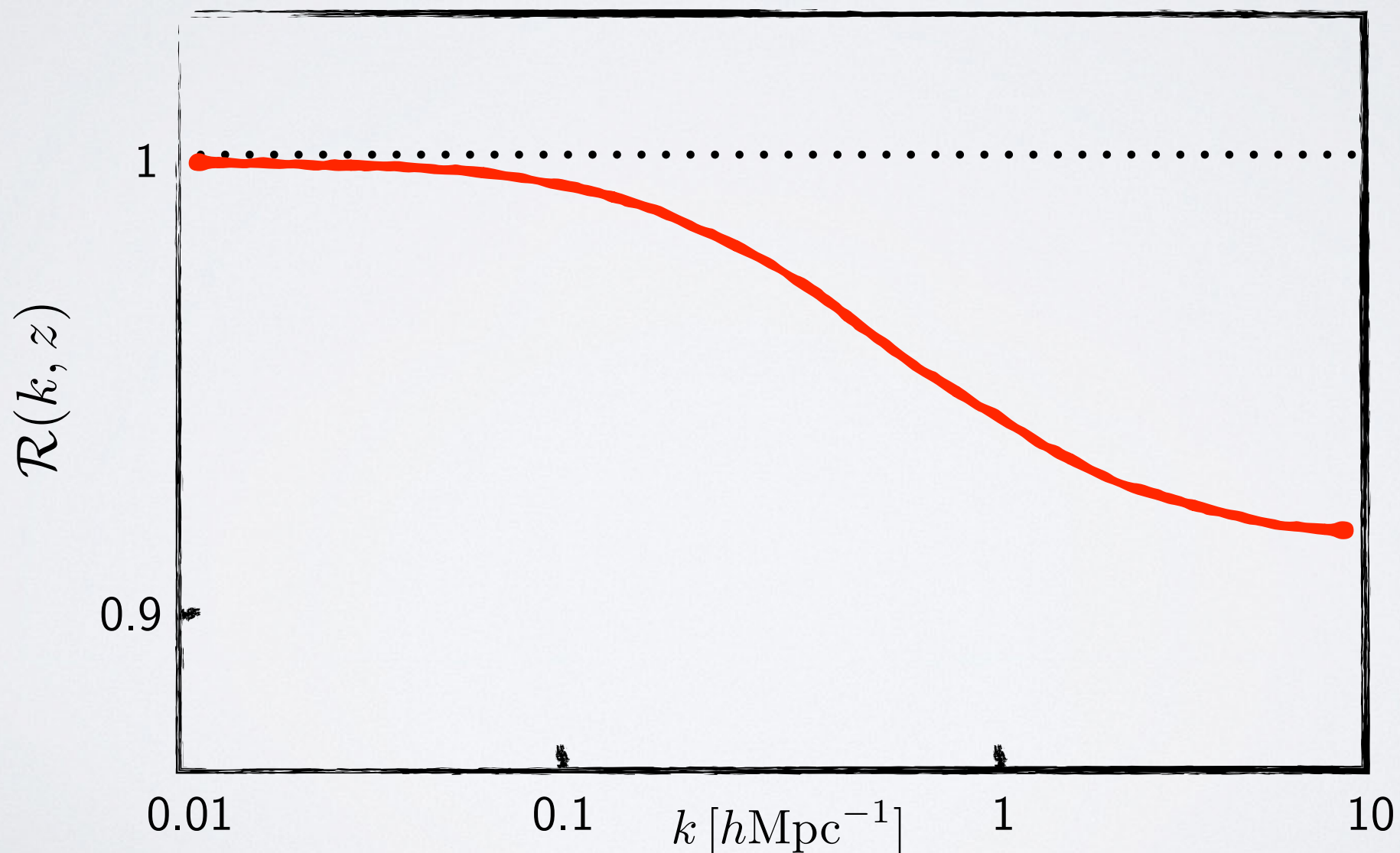
Λ CDM cosmology with ICs adjusted to
match

real beyond- Λ CDM cosmology $P_{\text{lin}}(k, z_0)$

Halo Model Reactions

2) Reaction

$$\mathcal{R}(k, z) \equiv \frac{P_{\text{NL}}^{\text{real}}(k, z)}{P_{\text{NL}}^{\text{pseudo}}(k, z)} = \frac{P_{2\text{h}}^{\text{real}}(k, z) + P_{1\text{h}}^{\text{real}}(k, z)}{P_{2\text{h}}^{\text{pseudo}}(k, z) + P_{1\text{h}}^{\text{pseudo}}(k, z)}$$



Halo Model Reactions

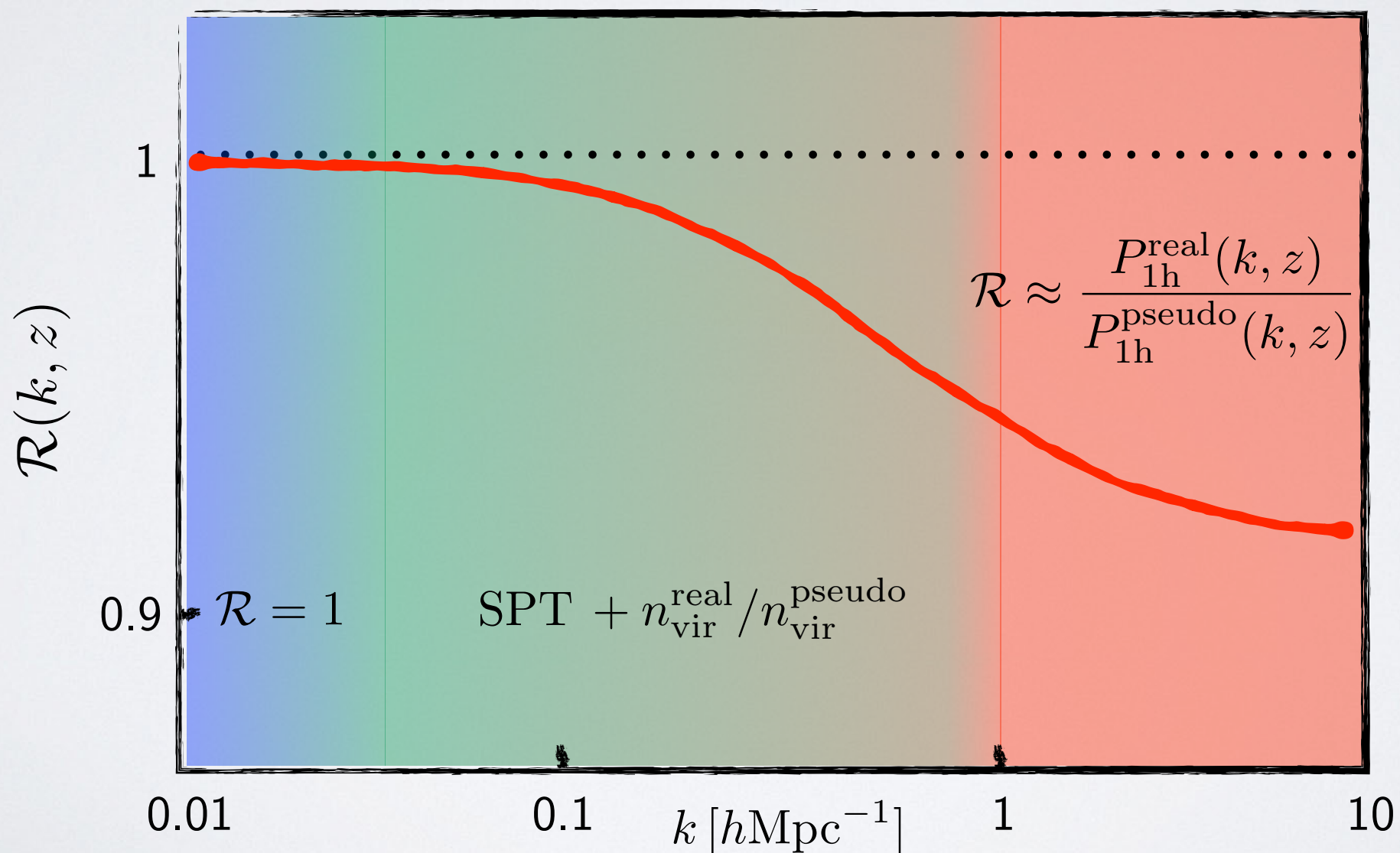
2) Reaction

$$\mathcal{R}(k, z) \equiv \frac{P_{\text{NL}}^{\text{real}}(k, z)}{P_{\text{NL}}^{\text{pseudo}}(k, z)} = \frac{P_{2\text{h}}^{\text{real}}(k, z) + P_{1\text{h}}^{\text{real}}(k, z)}{P_{2\text{h}}^{\text{pseudo}}(k, z) + P_{1\text{h}}^{\text{pseudo}}(k, z)}$$

large scales

intermediate scales

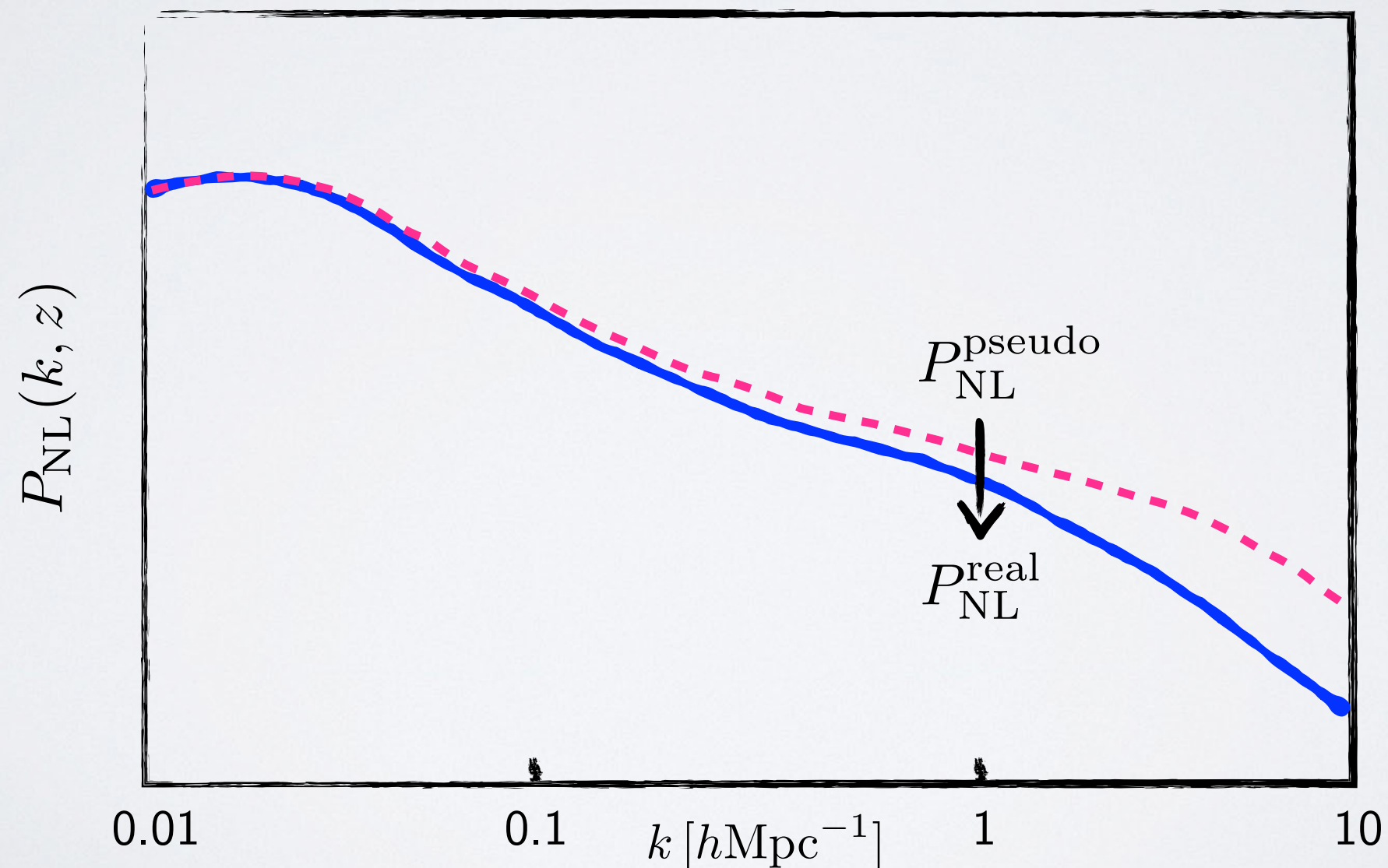
small scales



Halo Model Reactions

3) Power spectrum

$$P_{\text{NL}}^{\text{real}}(k, z) = \mathcal{R}(k, z) \times P_{\text{NL}}^{\text{pseudo}}(k, z)$$



Halo Model Reactions

1) *Pseudo* cosmology

Λ CDM cosmology with ICs adjusted to match **real beyond- Λ CDM** cosmology

$$P_{\text{lin}}(k, z_0)$$

2) *Reaction*

$$\mathcal{R}(k, z) \equiv \frac{P_{\text{NL}}^{\text{real}}(k, z)}{P_{\text{NL}}^{\text{pseudo}}(k, z)} = \frac{P_{2\text{h}}^{\text{real}}(k, z) + P_{1\text{h}}^{\text{real}}(k, z)}{P_{2\text{h}}^{\text{pseudo}}(k, z) + P_{1\text{h}}^{\text{pseudo}}(k, z)}$$

large scales: $\mathcal{R} = 1$

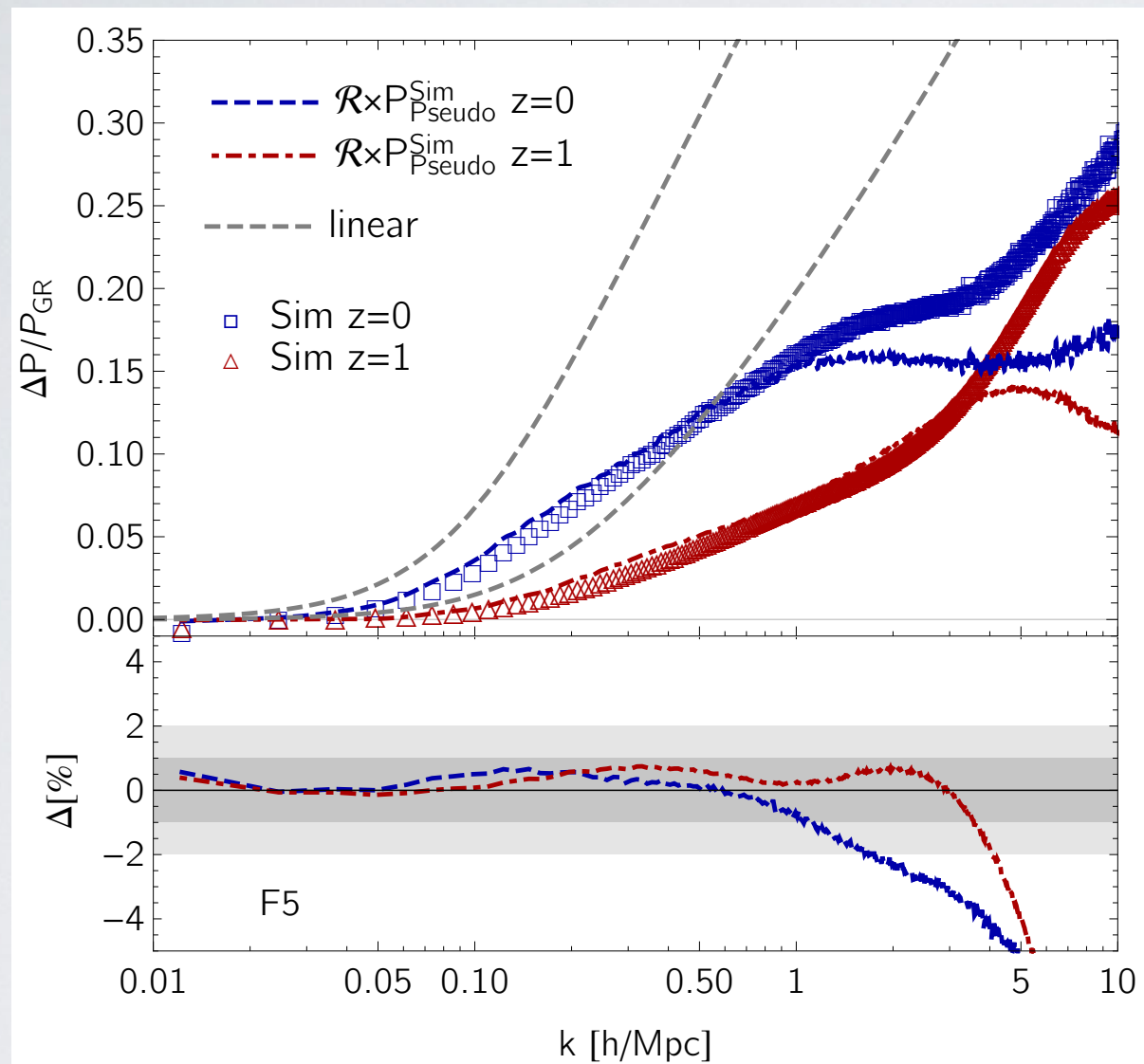
intermediate scales: $\text{SPT} + n_{\text{vir}}^{\text{real}} / n_{\text{vir}}^{\text{pseudo}}$

small scales: $\mathcal{R} \approx \frac{P_{1\text{h}}^{\text{real}}(k, z)}{P_{1\text{h}}^{\text{pseudo}}(k, z)}$

3) Power spectrum

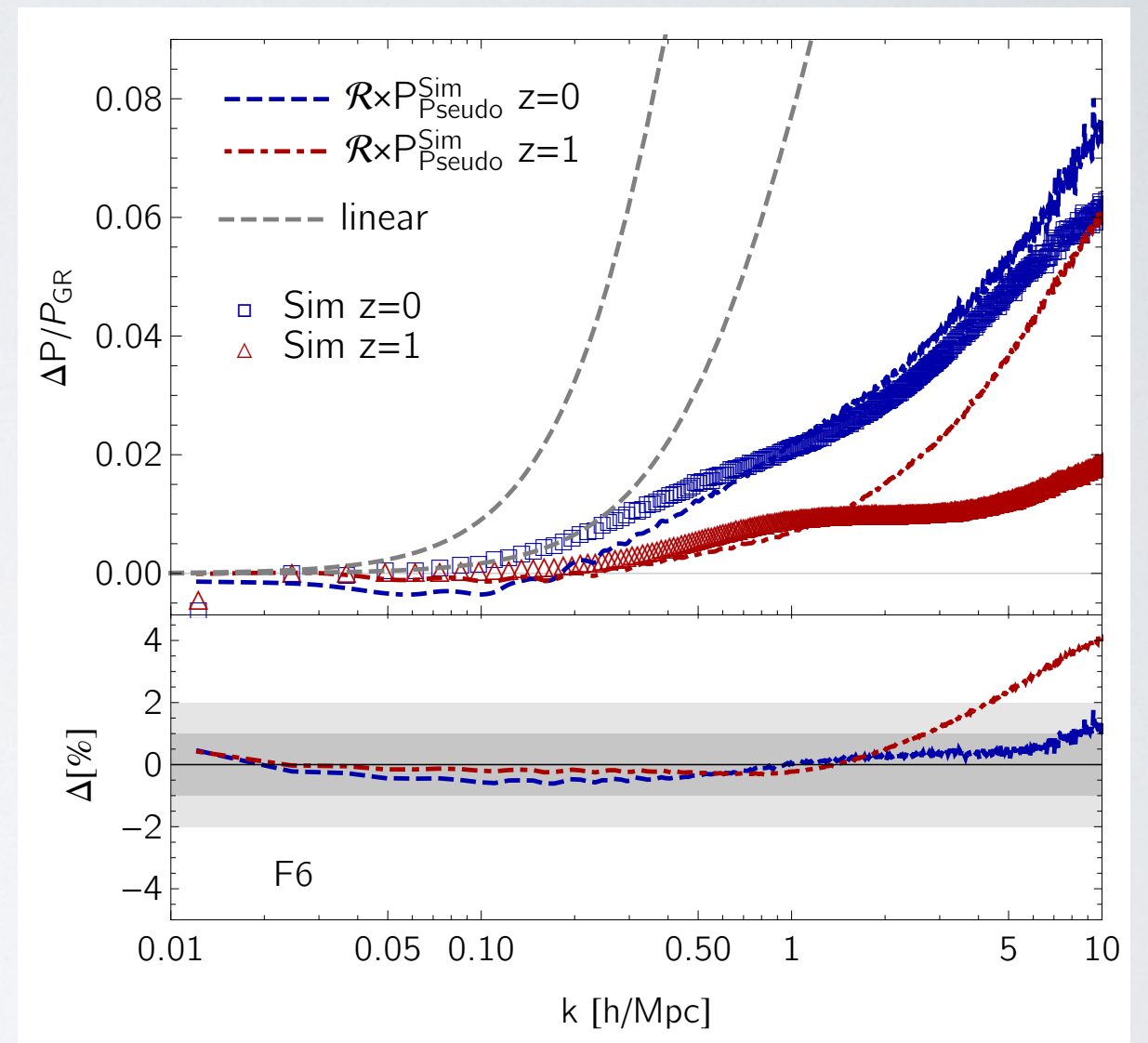
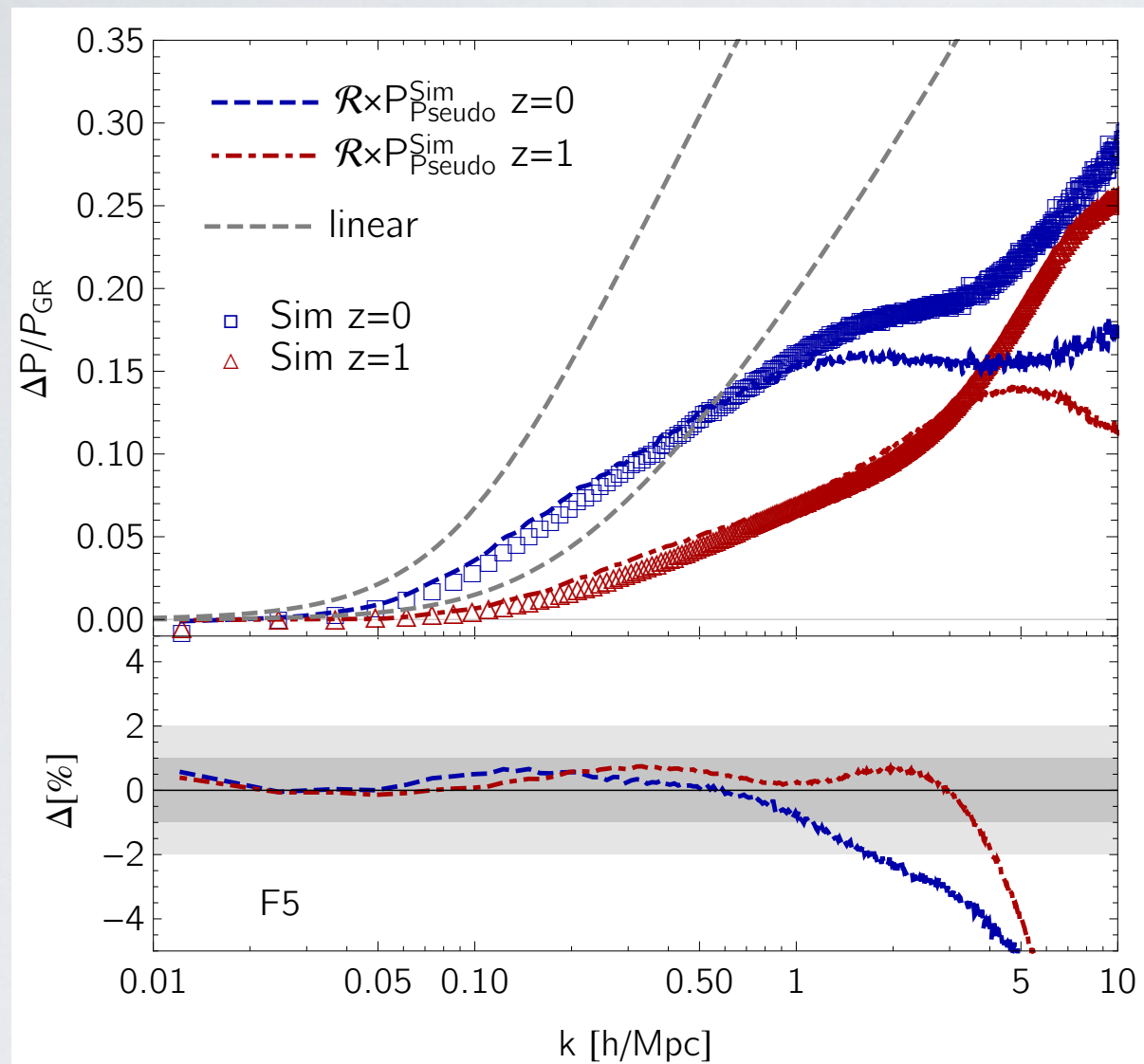
$$P_{\text{NL}}^{\text{real}}(k, z) = \mathcal{R}(k, z) \times P_{\text{NL}}^{\text{pseudo}}(k, z)$$

$f(R)$ Gravity



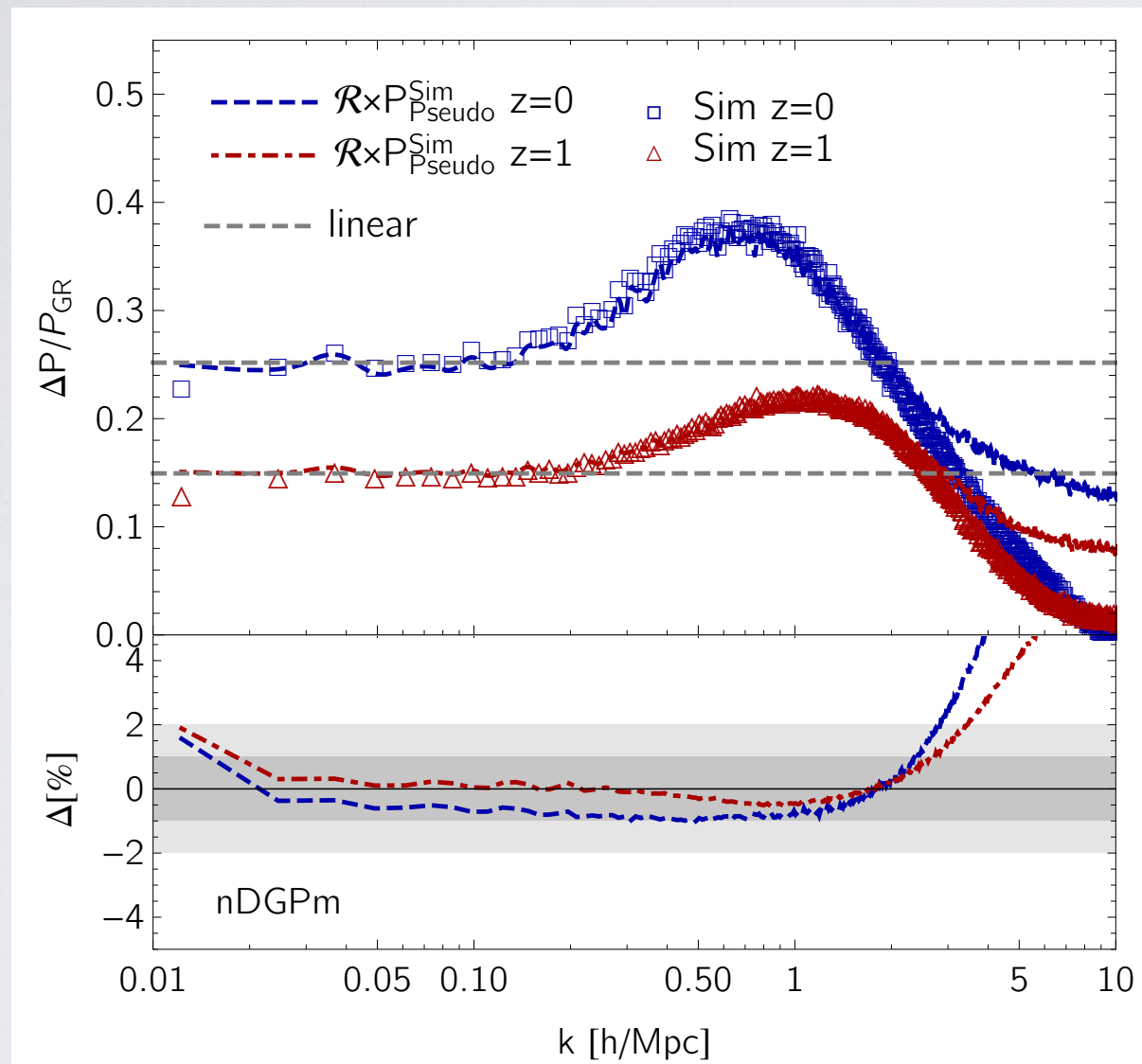
Cataneo+ 2018a in prep.

$f(R)$ Gravity



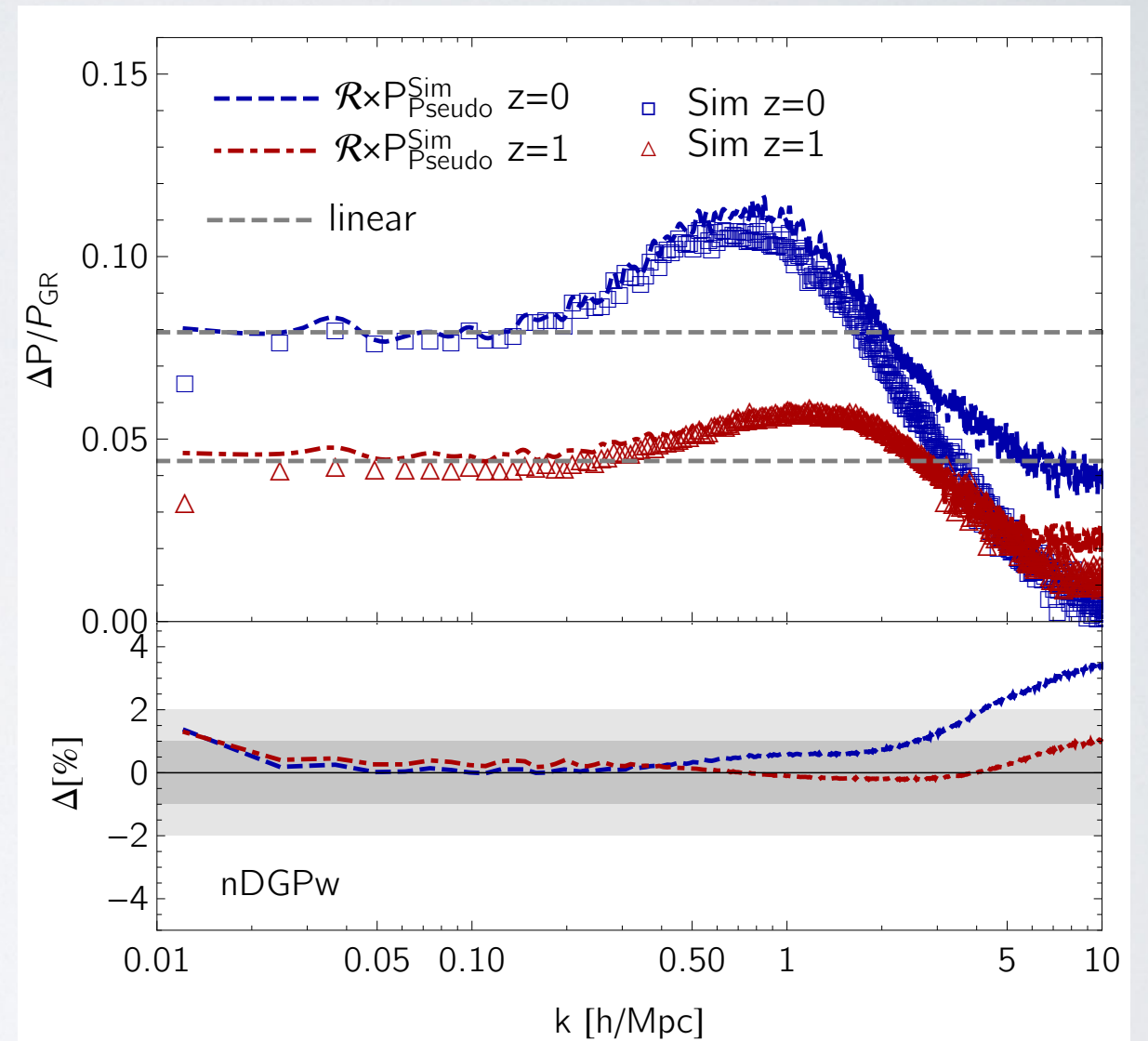
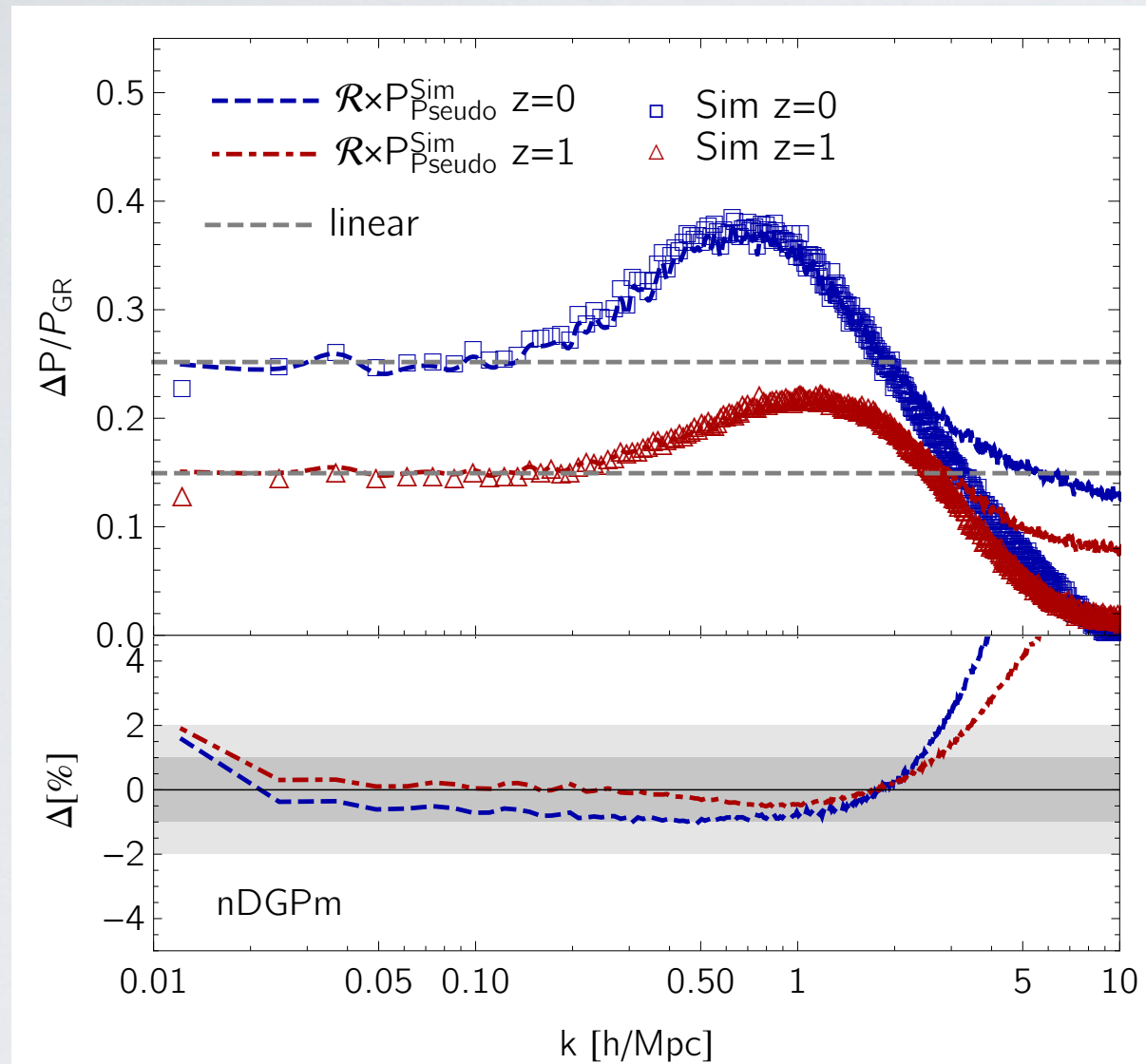
Cataneo+ 2018a in prep.

nDGP



Cataneo+ 2018a in prep.

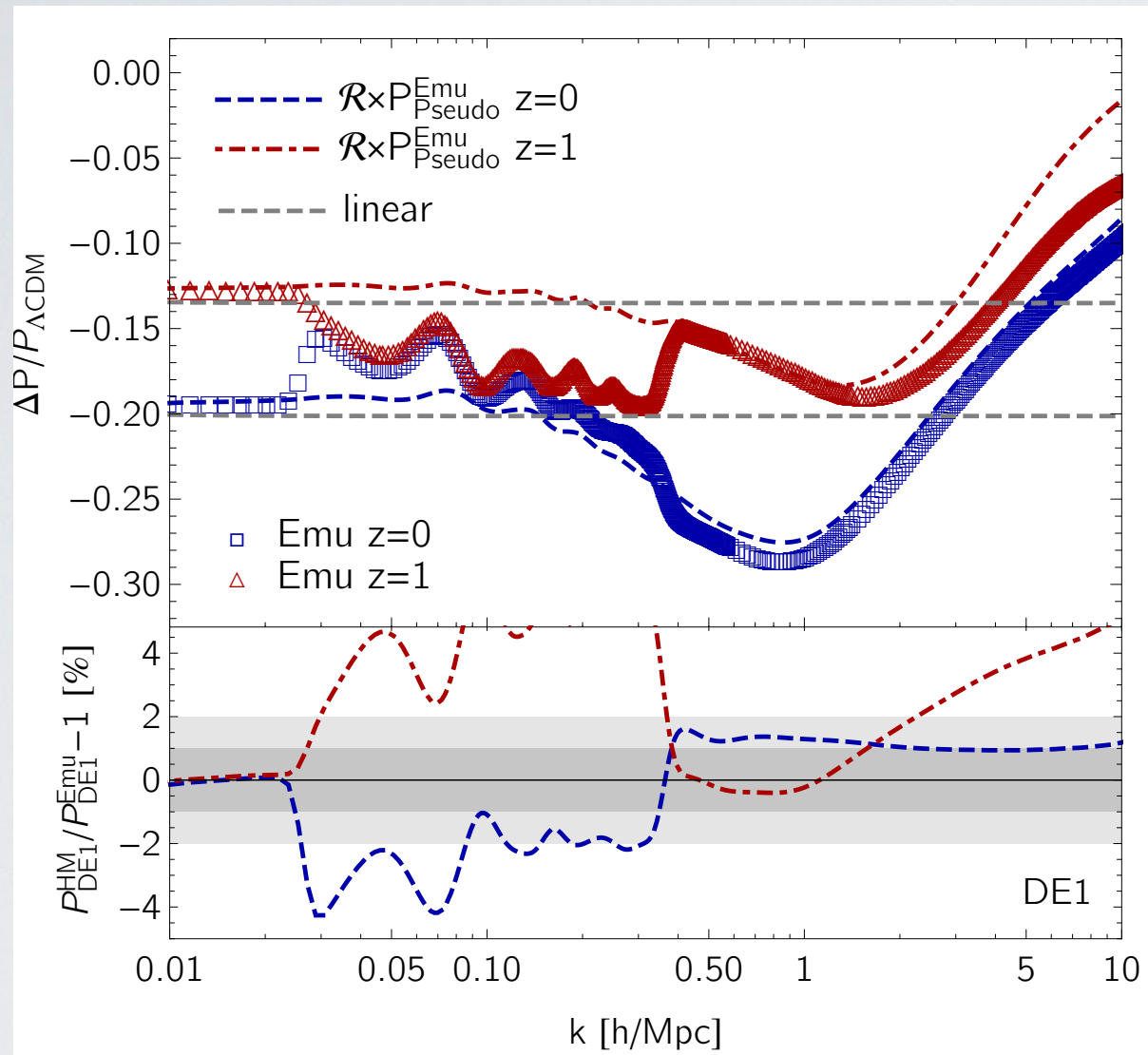
nDGP



Cataneo+ 2018a in prep.

Evolving DE

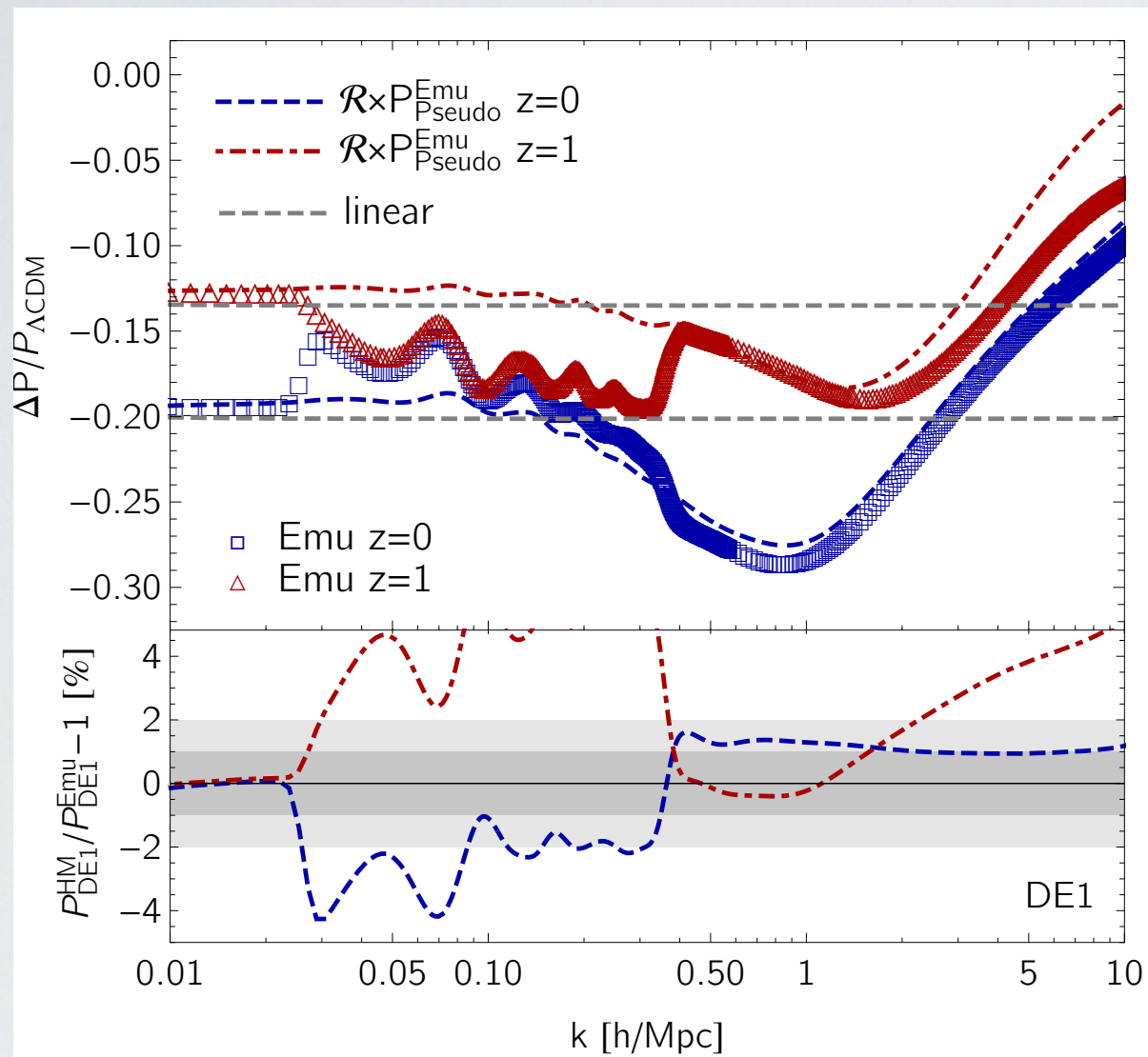
Cataneo+ 2018a in prep.



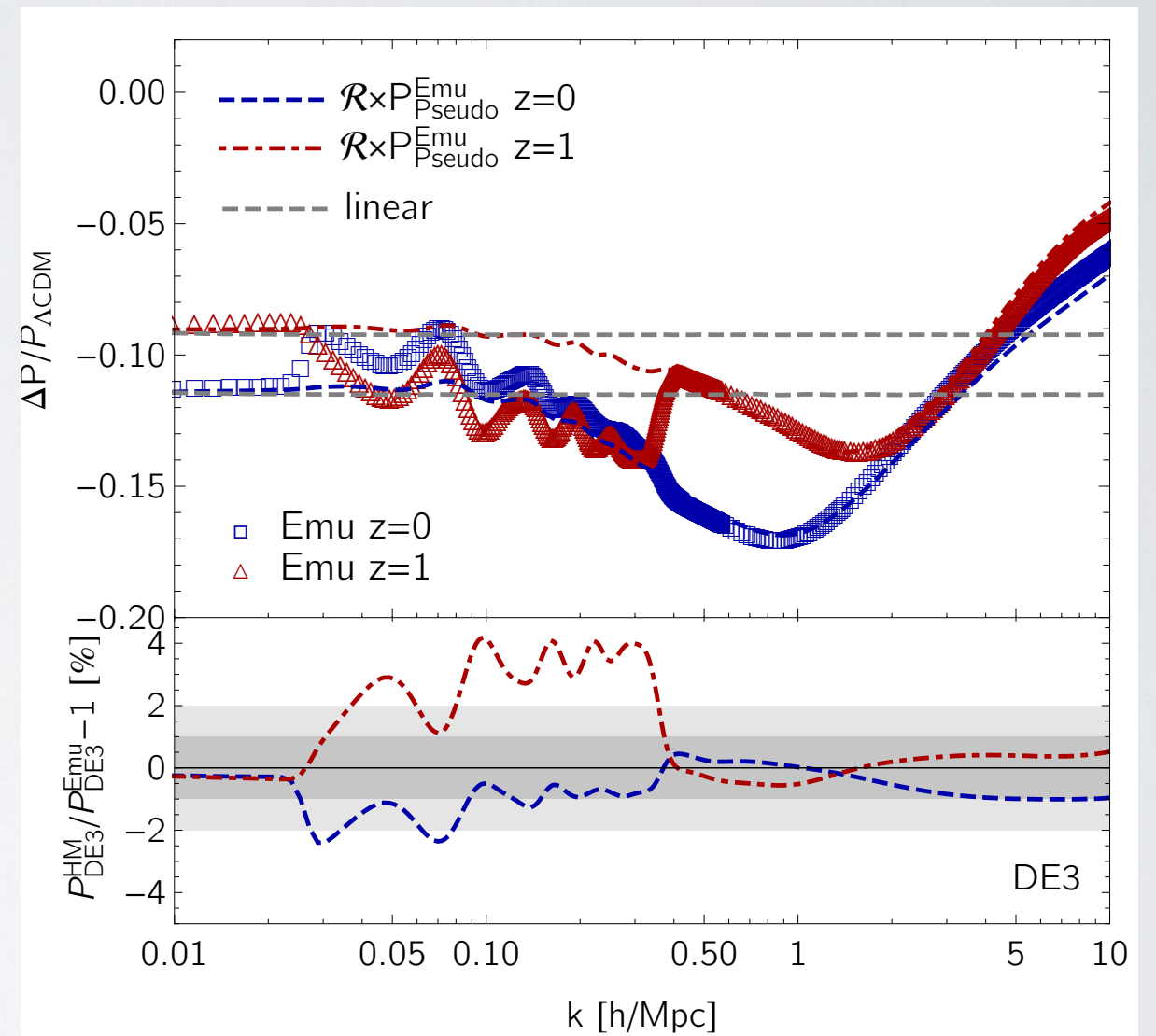
$(w_0 = -0.7)$

Evolving DE

Cataneo+ 2018a in prep.

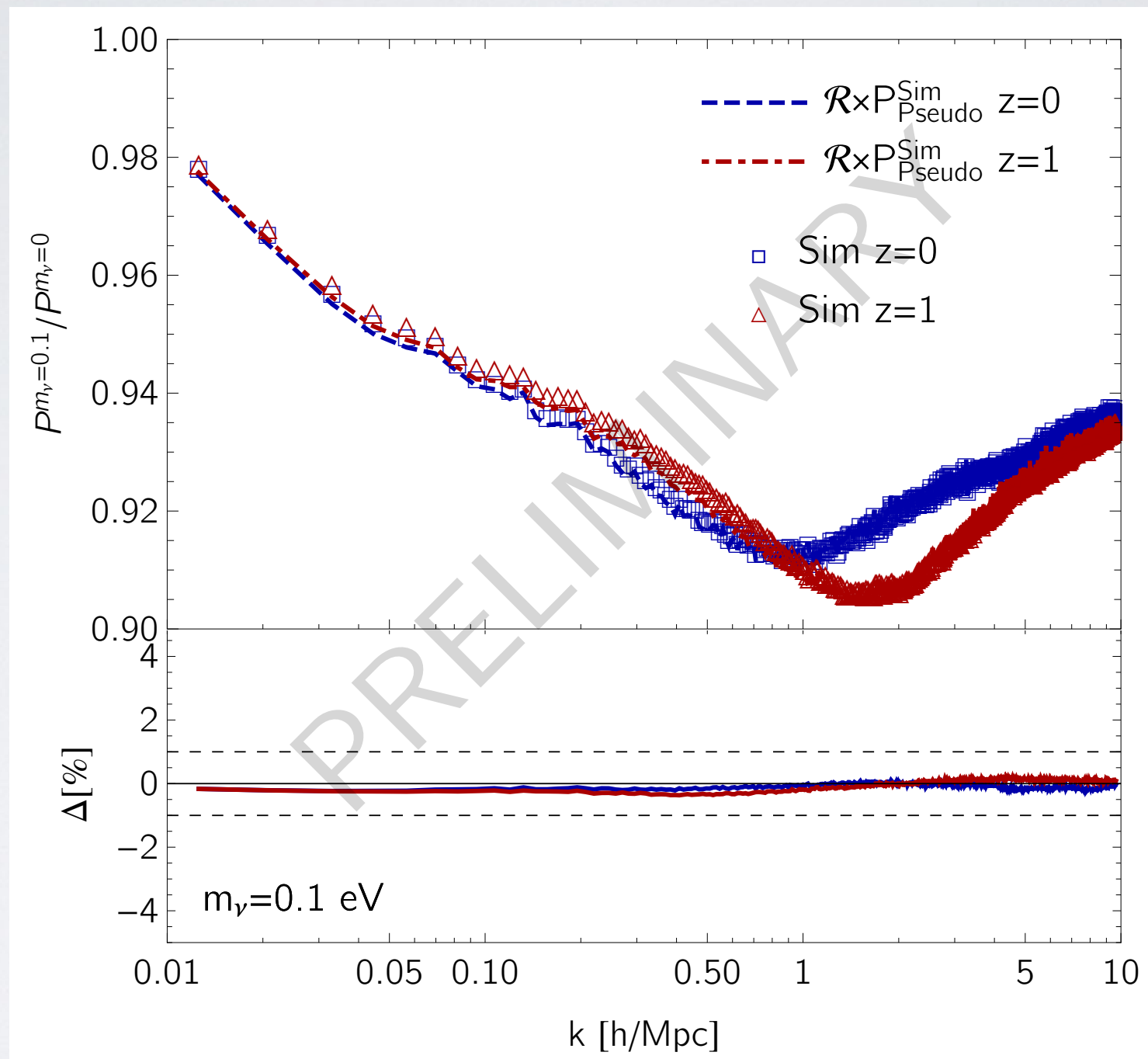


$(w_0 = -0.7)$



$(w_0 = -1 \quad w_a = 0.5)$

Massive Neutrinos



Cataneo+ 2018b in prep.

Summary & Outlook

- Halo model reactions are:

- ☒ Fast (runtime ~seconds)
 - ☒ Versatile (Λ CDM extensions)
 - ☒ Accurate ($\approx 1\%$ for $k < 1 \text{ h/Mpc}$)
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- Improve highly non-linear regime ($1 < k \text{ Mpc/h} < 10$)
- Build *pseudo* cosmology emulator
- Include baryonic physics
- Extend to Horndeski theory
- Explore degeneracies in physics beyond vanilla Λ CDM